NEUTRINOS AND BEYOND

New Windows on Nature

Neutrino Facilities Assessment Committee
Board on Physics and Astronomy
Division on Engineering and Physical Sciences

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Washington, D.C.
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This project was supported by Grant No. PHY-0223181 between the National Academy of Sciences and the National Science Foundation. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-08716-3 (book)
International Standard Book Number 0-309-50634-4 (PDF)

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Cover: The Super-Kamiokande Detector. Courtesy of the Kamioka Observatory, Institute for Cosmic Ray Research (ICRR), University of Tokyo.

Printed in the United States of America

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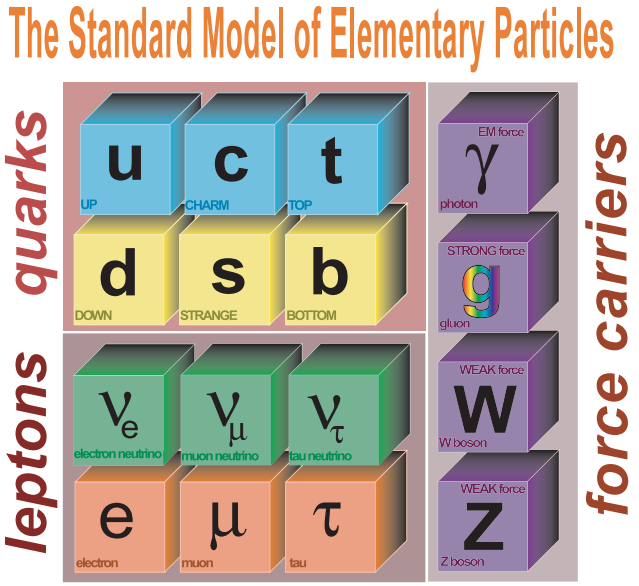

FIGURE 2.1.1 The Standard Model of particle physics describes the basic building blocks of the universe and the rules governing their interactions. This chart displays the basic quarks and leptons that make up matter and the four force-carrying boson particles. For each so-called family (columns in the chart), there are two quarks (an up type and a down type) and two leptons (a neutrino and an associated partner lepton). The neutrinos have been the most elusive part of the Standard Model because of their minimalist character—they were posited to interact only very weakly, to be massless, and to be independent of one another. Recent experiments have shown that neutrinos do in fact have mass, and that they can transform into one another. Figure courtesy of Paul Nienaber and Andrew Finn, BooNE Collaboration.

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SIDEBAR 2.1 CONTINUED

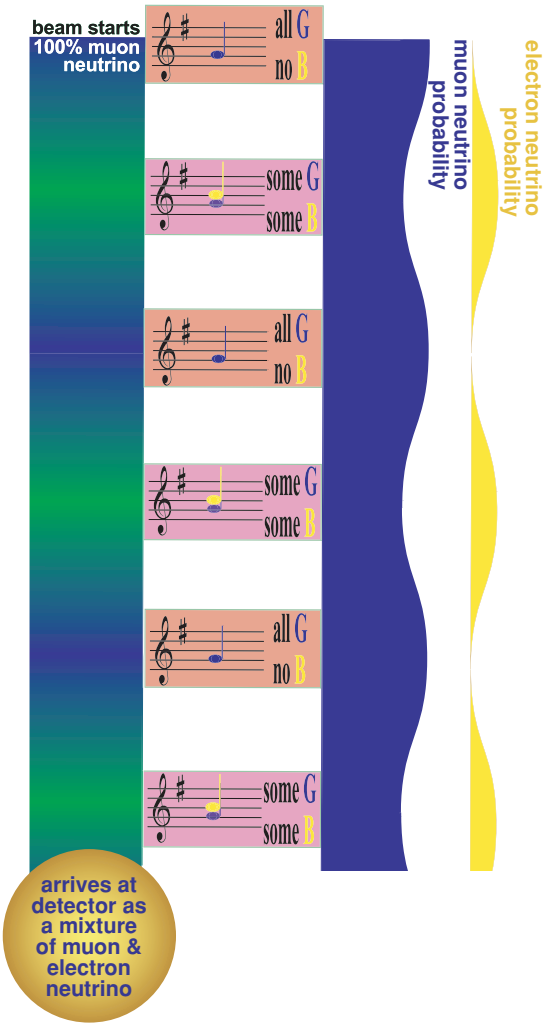

FIGURE 2.1.2 As described in the text, neutrinos have been shown to oscillate—an observation that shows, in effect, that they have mass. Understanding neutrino oscillations requires a trip into the world of quantum mechanics; this figure uses a musical analogy to represent the behavior of a simplified model. Imagine only two neutrinos that can oscillate into one another, and imagine representing each neutrino as a musical pitch. Further assume that only one pitch at a time can be detected. Let the muon-neutrino be represented by a G-note and the electron-neutrino by, say, a B-note. In the absence of neutrino oscillations, one could assume that a G-note originated as a G and would remain forever a G, and likewise for a B. However, with the possibility of neutrino oscillations, a muon-neutrino G-note can "de-tune" into a B-note as time passes, and vice versa. Since only one pitch at a time can be detected, the neutrino will sometimes "sound" like a G and sometimes like a B; the rate of de-tuning is related to the neutrino mixing parameters. The probability of observing the muon-neutrino as an electron-neutrino varies as a function of time (or distance if the neutrino is traveling), as shown by the sinusoidal curves alongside the scales. The detailed properties of neutrino oscillations are important to understanding how the Standard Model particles interact and how galaxies and the universe work. Figure courtesy of Paul Nienaber and Andrew Finn, BooNE Collaboration.

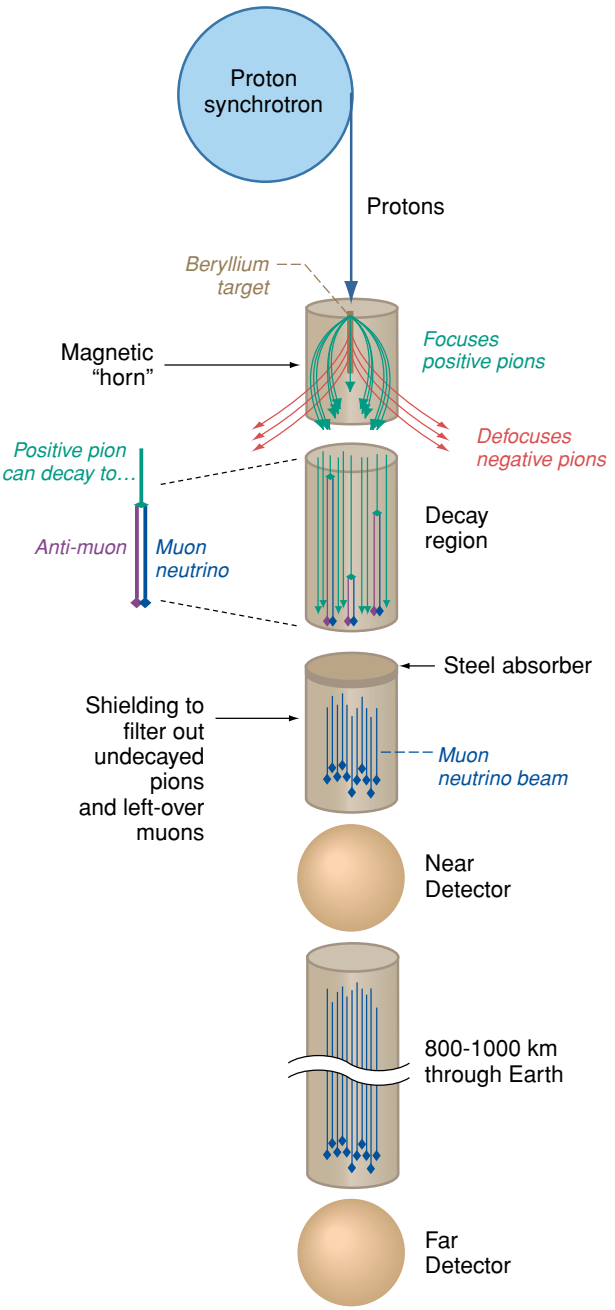

FIGURE 4.3 Shown here is one depiction of a long-baseline neutrino oscillation experiment. The neutrino beam is produced by focusing an intense beam of high-energy protons on a proton-rich target such as beryllium. The particle debris is cleaned and focused by a powerful electromagnetic system called a magnetic horn. The resulting beam consists of almost entirely pions, which will decay in flight into muons and muon-neutrinos. A steel absorber is used to stop the remaining pions and newly born muons. In the long-baseline experiment, the berm of earth in the figure is actually formed by Earth itself; a neutrino beam would travel thousands of kilometers before arriving at the target, where the neutrinos are detected and identified by their interactions with the detector. Figure inspired by illustrations from Prof. Paul Nienaber and undergraduate Andrew Finn, BooNE Collaboration.